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Winter Injury of Fruit Trees in Ohio

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OHIO
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Fig. 1.—Delicious apple tree showing common type of trunk injury following winter of 1935-36

WINTER INJURY OF FRUIT TREES IN OHIO

LEON HAVIS AND I. P. LEWIS[1]

This bulletin contains a detailed report of the injury to Ohio fruit trees during the winter of 1935-36, as well as brief accounts of other severe winters in which damage is known to have occurred. The authors base the material of the bulletin on information secured from the 18 most severe winters in Ohio during the last 167 years, on a survey of the injury during the winter of 1935-36, and on literature pertaining directly to injury like that observed in Ohio.

Winter injury is a serious problem for Ohio fruitgrowers. The amount of injury, as well as the recovery, depends on many factors. Often the damage is not evident at once, but may continue to appear for several years after the occurrence of the low temperature. The years of greatest damage have been rather irregular.

Probably the most destruction to trees in the history of fruitgrowing in the State occurred in the winter of 1935-36. Certain sections of the State suffered their greatest losses that winter. With few exceptions, mostly along Lake Erie, all orchards in Ohio suffered to some extent. Other states were also affected, and special reports of the injury have been prepared by workers in some of them, including Pennsylvania (2) and Maine (18).

When it became obvious during the late winter and early spring of 1936 that many trees were dead and others injured, the authors began a survey of the damage to determine the amount of injury and the conditions affecting its type and severity.

The literature on winter injury contains many theories and postulations which are too often based entirely on a single severe winter. There has been some investigation carried on under controlled conditions, and much more seems necessary before the factors associated with winter injury can be definitely understood and classified. Many of the results have been inconsistent.

ACCOUNTS OF SEVERE WINTERS IN OHIO

It seemed advisable in this study to consider as many severe Ohio winters as possible, especially those in which much injury to fruit trees occurred. It seemed that the relative importance of the various factors associated with injury could be determined more closely if a large number of winters were studied.

By going through early histories, old farm journals, Weather Bureau reports, reports of the State Department of Agriculture, Ohio Pomological and later Horticultural Society reports, as well as several other sources, the senior author was able to trace the Ohio winters from 1771 to the present—a period of 167 years. Until 1788, however, the information was scattered, and only parts of the State were included in the various reports.

[1]The authors appreciate the suggestions of J. H. Gourley, F. S. Howlett, and C. W. Ellenwood of the Station Staff, also those of F. H. Beach, Extension Specialist, Ohio State University, in the preparation of the manuscript.

There were, of course, other winters than the 18 described as severe for fruit trees in which trees in certain parts of the State were badly injured. Almost every year the fruit buds of the tender fruits are at least partially destroyed in some part of the State. In fact it is an unusual year in which no winter injury occurs in Ohio.

1796-97

The winter of 1796-97 was relatively severe. Records at Cincinnati show that the temperature reached —18° F. in January of 1797. There was severe injury to many trees and shrubs and to such fruit trees as were grown. An earlier winter, that of 1779-80, had evidently been severe also, although little is known of its effect on fruit trees, since few were grown in Ohio then. Alexander (1) notes: "The winter of 1779-80 is spoken of as one of remarkable severity. Snow fell in the Muskingum Valley to the depth of two feet....." Partridges and squirrels are reported to have frozen in the woods.

1817-18

There was little injury to fruit trees for 21 years after the winter of 1796-97. The next severe winter occurred in 1817-18 when there were many more fruit trees in the State. February of 1818 was severe. The minimum temperature recorded was —22° F. on February 10. Both forest and fruit trees suffered in southern Ohio.

Dr. S. P. Hildreth, who kept detailed records of the weather during that period, wrote describing the severe February: "So intense was the cold that there was a continual cracking and snapping by the contraction of wood in buildings and trees. Peach trees, sassafras, and spice-bush were either killed or materially injured generally throughout this country. The weather was colder at this time by 10 or 12 degrees than has been known since the country was first inhabited."

1831-32

The entire year of 1831 was below normal in temperature. In fact, the average for the year is the lowest on record. That year the average for College Hill, Cincinnati, was 48° F.; it is usually about 53° F. The temperature in January 1831 reached a minimum of about —10° F., but little injury other than fruit bud killing of most peaches was reported. December 1831 was described as the coldest December "within the memory of the oldest inhabitants." A temperature of —10° F. was recorded on December 15 at Cincinnati. This was probably the coldest December, as a whole, since Cincinnati was founded in 1788, with one possible exception (December 1917).

The severe temperatures continued into January 1832, when there was a heavy snow. The thaw occurred during the latter part of January.

Mr. J. H. Jackson of Cincinnati noted in his "Meteorological Register" that the peaches bloomed February 5 in 1832. However, Dr. Hildreth of Marietta wrote of the spring of 1832: "The spring was very cold and backward, so that half the season was passed before the winter had fairly left us. Peach trees, where the cold had spared them, did not blossom till the middle of April, and apples not until the 25th, which was 20 days later than is common in this locality. It is with us pretty well established as a maxim, that the colder the winter the more backward the ensuing spring, and the later the spring the

greater the certainty of fine crops of fruit, as was demonstrated in the productions of the year 1832, and of the previous years when after an intensely cold winter and backward spring, many kinds of fruit were very abundant." Although this is not necessarily true, it shows the opinions at that time.

1834-35

The entire winter of 1834-35 was relatively cold, but the damage to fruit trees was not as great as expected. The lowest temperature at Cincinnati, —17° F., occurred on February 8. That record stood until February 1899. Although peaches were scarce and there was considerable injury to many peach trees, the apples were not severely injured.

1855-56

The winter of 1855-56 was unusually severe in the amount of winter injury. The Ohio Agricultural Report for 1857, written in June 1858, stated: "An unusually large number of fruit trees had been planted that season (1855) most of which perished before the end of summer. Next followed the extraordinary severe winter of 1855-56 which was the most disastrous to fruit trees of any winter that ever occurred in Ohio—killing nearly all the peach trees outright, and many of the apple, pear, cherry, grape, etc. At first it was supposed that no very general injury had been done to apple trees as they did not show the extent of the mischief as soon as others. But before the end of summer many of the trees in most orchards gave unmistakable evidence of disease, the cause of which could only be attributed to the past winter. Again the following year, and up to the present time, many apple trees have continued to sicken and die; no doubt from the same cause, so that many persons have concluded that all the orchards that were of bearing age at the time of the hard winter received such injury therefrom as will cause them prematurely to decay." In the same article it is also stated that "it may be safely asserted that in no other state has there been so large an amount of money expended during the past 10 years in the purchase of fruit trees."

Alexander (1) noted: "The winter of 1855-56 was the longest and most severe within the memory of the oldest inhabitants. Near zero weather prevailed for about two months, the lowest being 2° below in December, 14° below in January, and 13° below in February."

The Miami River at Hamilton, Ohio, was frozen over on November 4 and remained so until February 22; the Ohio River at Cincinnati was frozen over from January 15 to February 2.

Soon after this severe winter a writer stated: "On sandy lands along the lake shore and on elevated free stone ridges in the southeast quarter of the State, the trees have generally escaped injury by the winters."

1863-64

The next winter which may be called severe for fruit trees occurred in 1863-64. This winter was unique in that there was only one day of very low temperature, January 1. The intense cold (—12° F. at Cincinnati) resulted in considerable damage throughout the Mississippi Valley. The temperature dropped from above freezing on December 31 to —10 to —20° F. through the Middle West on January 1 (—24° F. at St. Louis, —16° at Memphis, —28° at Chicago). The southern part of Ohio was affected more than the northern sections.

Dr. J. A. Warder, prominent Ohio horticulturist, speaking at the annual meeting of the Ohio Pomological Society at Painesville in December 1865 stated of the severe January of 1864: "We are now near the eastern limits of its severity, and the evidence is before us in the healthful orchards, the living plants, and these beautiful fruits, that you have not suffered so severely as some of us who you had supposed were enjoying summer skies and more genial climate (at Cincinnati)."

The peach fruit buds were killed even in Painesville that year, however, for Dr. Beardslee (of Painesville) stated at the same meeting: "..... the very severe storm of January 1854 destroyed all the peaches and all the cherries of our village and vicinity." He stated further: "In my residence of nearly twenty years in Ohio, I recollect two seasons only in which the delicate fruits, after escaping injury during the winter, have been destroyed extremely by frost in the spring."

The comparative lack of injury of fruit along Lake Erie in 1864 and the almost no injury during the slightly less severe winter of 1865-66 caused many growers to plant extensively to the more tender fruits on the lake shore.

1872-73 AND 1874-75

The winter of 1872-73 was relatively cold throughout Ohio, but the amount of tree killing was not as widespread as during the winter of 1874-75. The severe injury to trees during the latter winter seemed to be accentuated by the drouth in the late summer and fall of 1874, also by the heavy crop of that year.

"Apples, pears, peaches, and plums were nearly an entire failure in most of the central and southern parts of the State", according to a statement in the Ohio Horticultural Society report of 1875. In the same publication there is also the statement that "in the northern parts of the State, especially the northwest, there was a fair crop of apples and pears and a half crop of grapes."

The winter of 1874-75 caused much root injury to unprotected trees. The value of cover crops or snow was especially well demonstrated that winter. Many orchards on hills with no protection suffered considerably. Trees in sod showed much less injury than those in cultivation.

1878-79

Although the temperature fell to from —15 to —20° F. throughout most of the State on January 3, 4, and 5, 1879, no great amount of permanent injury resulted except in a few localities in the State. Except in the lake region the peach, cherry, and plum crop was almost entirely destroyed. Some of the older peach trees were injured.

Mr. G. W. Campbell of Delaware, Ohio, reported in the Ohio State Horticultural Society report of 1879: "A winter of unusual severity destroyed a large proportion of the fruit buds, and injured many trees; so that all kinds of orchard fruits have been very scarce, and some kinds entirely wanting. Fortunately, during the severest portion of the winter, the ground was covered with snow, protecting strawberry plants, and also the roots of grapevines, and some trees and shrubbery whose tops were killed." Mr. Campbell also stated: "Grapevines did not escape the general injury from the excessive and long continued severity of the past winter, and the fruit buds were killed upon all except the hardiest of the 'iron-clad' varieties, and even these were more or less injured."

Mr. N. Ohmer of Dayton stated at the same meeting: "Strange to say, the extreme cold weather of last winter did but little damage to fruit, except it be peaches and cherries."

Mr. G. H. Miller of Norwich wrote: "We see the effect of the severe winter on the trees, in many cases the old trees being entirely killed, and even young orchards of 5 or 6 years' growth appear to be injured by bursting of the wood in the trunk and branches."

The winter of 1878-79 was a good example of a severe one following a fall in which the trees were as well matured as could be expected in most sections. The low temperature, in itself, rather than a combination of low temperature and lack of maturity, seemed to be mainly responsible for the injury that winter.

1880-81

In some sections of the State the winter of 1880-81 was the most severe since 1856. The summer of 1880 was known as a wet one for Ohio, and a rainfall of 54.67 inches was recorded in Cincinnati that year, the largest annual amount since 1847. The following November was one of the coldest on record. A temperature of —12° F. was recorded on the morning of November 19 at Cincinnati; this was by far the most severe temperature recorded there during the winter.

The following quotations are taken from reports made at the Horticultural Society meeting in December 1881:

From southeastern Ohio: "Peach trees, in unfavorable localities, that were exhausted by the excessive crop of the previous year, were in most cases destroyed by the severe winter; and grapevines in low situations were, in many instances, killed back to the ground or to the snow line."

From central Ohio: "The winter of 1880-81 was an unusually severe one for our State; more so, indeed, than anyone since 1856. This severe cold materially injured most kinds of fruit-bearing trees. The severe winter was followed by one of the driest summers in Central Ohio since 1838. This extreme drouth had a very bad effect on the winter-injured trees."

From northern Ohio: "The unusually severe winter of 1880-81 had a disastrous effect on the fruit crop of the past season." The writer mentioned "the excessive hot, dry weather and the ever present insect enemies." He reported no peaches in Northern Ohio except "between Sandusky and Toledo there was a fair crop with a small yield in occasional favored locations on the mainland."

From N. Ohmer of Dayton, Ohio: "Never did I see such destruction, especially of apple trees. Whole orchards were entirely destroyed, and very few escaped injury. This general destruction of fruit trees was not so much on account of excessive cold (as we had colder weather in the winter of 1878-79, that is, the mercury sank lower), but on account of the sudden, extreme change when trees were not prepared for winter."

Probably the lack of maturity, as well as the drouth and heat the following summer, which is apparently the longest period of severe heat on record, accounted for the widespread injury to trees.

1883-84

Only 4 years after the previously described severe winter, another one occurred. The temperature reached —20° F. on January 5, 1884, at Cincinnati and —32° F. at Delaware. A report from Lucas County placed the minimum at —32° F. on January 25.

The apple crop had been fairly light during the previous 2 years, and according to reports, "the young wood and buds of last year's growth being well ripened, were enabled to pass through the remarkably severe winter with comparatively slight injury." Peach and cherry fruit buds were generally killed, however, and some weak peach trees were destroyed.

Mr. W. W. Farnsworth of Lucas County wrote that "after a winter of such intense and oft recurring cold, the fruit grower naturally anticipated serious injury to tree, plant and shrub, especially when he remembered that the mercury stood at 32° below at one o'clock of the morning of the 25th of January and twelve hours later the snow was melting under the warmth of a bright sunny day." To his surprise, he found that much less injury than he expected had occurred.

The trees subjected to the low temperatures withstood the severe winter remarkably well, apparently because of their hardened condition. The previous fall had been fairly dry, and the trees were evidently well matured.

1884-85

The summer of 1884 was noted as relatively dry. "This was followed by the most severe winter ever known in the history of Ohio", according to a report at the State Horticultural Society meeting in December 1885. In Richland County it was reported that the temperature "dropped below zero 40 times during the winter and—at least a dozen times from 15° to 25° below." It was below zero for several successive days in March. Cuyahoga County reported —15.1° F. on February 11, and at the same time it was —10° F. at Cincinnati.

The peach and cherry fruit buds were killed that year, but it is remarkable that no more injury resulted. In only a few cases was there considerable injury to the trees. Probably the previous dry summer was partly responsible for the lack of severe injury.

Following this winter, Mr. W. W. Farnsworth of Lucas County wrote: "He who will inform us how to grow Baldwin apples on hardy, healthy trees will be a benefactor to mankind in general, and the orchardists of Northern Ohio in particular." Evidently Baldwins had been injured there during the last several severe winters.

1898-99

Probably there has been no other winter in the history of Ohio that was any more remarkable from the fruit viewpoint than that of 1898-99. Throughout the State as a whole, a great many minimum winter temperature records were broken, and February was apparently the coldest in the history of Ohio. The official minimum for the State (—39° F.) which remains today was registered at Milligan, Perry County, February 10, 1899. On the same date there was an unofficial temperature of —44° F. at Laceyville, Harrison County. The official minimum temperature was —28° F. at Dayton, —22° F. at Marion, —20° F. at Oberlin, —38° F. at McArthur, —22° F. at Marietta, —17° F. at Cincinnati, and —18° F. at Rocky Ridge.

Although there was considerable injury to fruit trees, especially to peaches, it is remarkable that there was no more injury. In Lucas County it was reported that the "apple crop for '99 was the largest for many years." From the same grower came the report, "Many plums, some cherry, and a few pears were killed by the severity of the winter and the orchards that had been cared for in the best possible manner, were injured the most. Many trees standing in grass or weeds escaping all injury."

Another grower wrote from Miami County, "In February.....for seven days.....the thermometer marked below zero.....lowest being 28° below. Ordinarily this low temperature would have been destructive, not only to blossom buds, but to the trees and vines themselves. That this did not occur was doubtless due to the perfect ripening of the wood the fall before and to the perfectly dormant condition of all buds at the time. As it was, the peach buds were all destroyed, as well as the tender plums, cherries, and pears; but the hardier plums, as the Japans, the Americanas, the Damsons, Lombard, and a few others, were practically unhurt in bud or wood while many of the older European sorts were killed in blossom and badly hurt in wood. All peach wood was badly 'browned'."

A grower from Dayton wrote the following December: "Sweet cherries that were planted in the fall were killed. Peach trees were either killed or badly crippled. No apparent injury to the apple."

It was said that one grower in Ottawa County "would accept a good cigar for all the peaches he would have" just after the severe February. It was soon found, however, that there were live buds generally scattered through most varieties, especially in the eastern part of Ottawa County. One grower there wrote that they had "been led to believe that the peach germ cannot withstand more than 12° to 15° below zero and then under the most favorable conditions. It seems after this season's experience, we may add about two degrees to the previously adhered-to limit." He also wrote that the fall of 1898 "was an ideal season for the proper maturing of both bud and wood. There was no unseasonable warm weather in late fall or early winter.....also ample moisture in the soil." He stated further: "Some orchards (peach) bore nearly a full crop, ...some were badly winter killed.....due to improperly drained land." The damage was confined to the roots and was not the result of freezing of the tops.

Mr. Cox of Lawrence County reported that "1899 has been fairly favorable for most fruits except peaches. We had five days in February that the thermometer registered from 20° to 30° below zero. Nearly all peach trees over 7 or 8 years old are dead. Trees 3 or 4 years old that were cut back and cultivated have made a good growth."

From Cuyahoga County came the report, "All varieties of fruit buds came through alive, except the peach..... I believe the trees killed were those injured by leaf curl the season before."

From Summit County a grower reported: "I might have forgotten that the thermometer went to —23° as very little result came from this low temperature." The peach trees were killed, but there was "a full crop of sweet cherries."

No point was more outstanding in the winter of 1898-99 than that of root injury to trees on cultivated soil. Apparently in no other winter was the value of a covering of sod, mulch, or cover crops demonstrated more clearly.

1903-4

The winter of 1903-4 was not one of extremely low temperatures. The minimum was —18° F. at Dayton, —1° F. at Cincinnati, —15° F. at Marion, —18° F. at Medina, and —14° F. at Rocky Ridge. There was, however, an unusually large amount of rainfall during the latter part of the summer and fall of 1903, and the low winter temperatures continued at almost the minimum during December, January, and into February.

This winter is to be remembered in Ohio mainly because of the great amount of killing of peach trees in Ottawa County. According to Green and Ballou (9) the great amount of injury was caused by the "prevailing low vitality of the trees", which in turn was caused by "San Jose scale, leaf curl, lack of nourishing plant food, imperfect drainage." There were also "exceptional causes of susceptibility" due to lack of maturity of the wood. These writers also stated: "Rarely was an injured tree found standing in sod; no injury was done where the surface of the soil beneath the trees, had been covered with even a very light mulch; little injury was done where trees stood in fairly well drained soil....." Apparently there was almost as much injury to the roots of peach trees as in 1898-99. Again the lesson regarding root protection was brought to the foreground.

1906-7

The great amount of injury during the winter of 1906-7 was doubtless due almost entirely to the low temperatures in early October 1906. Both August and September, 1906, were unusually warm, and the rainfall in August was the heaviest since 1888. There was a sharp drop in temperature on October 10, and the temperature registered 18 to 25° F. for about 2 days. Wherever the trees had made the most growth late in the season they were injured most.

According to Selby (15) the losses were "most conspicuous upon young apple orchards 5 years old or less." He also stated: "The Baldwin in the northern part of the State—and the Rome Beauty and Hubbardston in the southern portion have suffered most seriously. In some instances 90% or more of the young trees.....have been seriously injured."

In the State Horticultural Society Report for 1907 one grower wrote: "Fruit growing has been on the decrease for several years in Miami County. The past season has been an unusually hard one for those still depending on fruit for profit. Except in a few protected spots, apples, pears and cherries were a total failure."

In this winter probably more than in any other studied, the evidence points to the injury's being due to an early (October) freeze. No other extremely low temperatures occurred during that winter.

1911-12

The winter of 1911-12 was fairly severe. .....The minimum temperature for the State (ranging between —8 and —15° F.) occurred in January, and there were some low temperatures in February.

According to the Ohio Farmer of May 4, 1912, there had been "a considerable loss of orchard trees due to the severe winter and unripened condition in which they entered the winter because of the late rains." Young peach trees were apparently injured most. There were, however, a full crop of peaches on Catawba Island and a partial crop in southern Ohio. In the same article was the statement, "Hundreds of peach trees one to six years old have been killed. Pear trees have also suffered severely. Nurserymen have lost heavily on their one-year-old stock." With reference to southern Ohio this writer continued, "A fair crop in the more favored localities is assured. Cherry and plum trees have fared about the same way. The prospect for apples is fair in orchards that have had proper care. Uncared-for orchards that had heavy crops last year have a very light setting of buds."

In the Ohio Farmer of July 20, 1912, F. H. Ballou wrote: "The present condition seems to come from a combination of causes, chief among which are the heavy bearing and drouth of the past season, together with the imperfect pollination of last spring....."

It seems, based on the climatological data for 1911 and 1912, as well as on the previous quotations, that the low temperatures, in themselves, were not entirely responsible for the severe injury to trees. The drouth early in the season of 1911 followed by the heavy rains in the latter part of the season was doubtless at least partly responsible. The resulting late growth caused the trees to go into the winter in a "soft" or immature condition. This was shown partly by the relative severity of killing of young trees during that winter.

1917-18

The winter of 1917-18 was the coldest, throughout Ohio as a whole, of any winter recorded in the State. The period of low temperature began December 8, 1917, and continued until February 5, 1918, and was undoubtedly the longest and severest on record at most of the stations. In Ohio as a whole, January 12, 1918, was the coldest day on record. Some of the minimum official Weather Bureau temperature records during the winter were:

	December 1917	January 1918	February 1918
	° F.	° F.	° F.
Cincinnati	−13	−16	− 5
Cleveland	− 8	− 9	−12
Columbus	− 9	−13	−10
Toledo	−10	−15	−13
Marion	−14	−16	−15
Circleville	−15	−20	−10
Vickery	−16	−13	−24
McArthur	−27	−23	−14
Wooster	−19	−19	−18

It may be noted that Ottawa County did not escape severe injury that winter. The destruction of older peach trees was widespread. Injury to branches, trunks, and crotches of apple trees was severe in almost all parts of the State. The injury was accentuated by the short and late growing season of 1917 which caused many of the trees to be immature. The lack of maturity of leaf buds was indicated by the following statements of Professor Paddock at the Ohio State Horticultural Society meeting in July 1918: "The idea of peach fruit set on dead wood is something I would not have believed if I had not seen it. There it is, peaches hanging on dead wood today. .....you cannot get peach buds too immature when they go into the winter, but you can get peach wood too green."

A fruitgrower of Lawrence County wrote in the Ohio Farmer of February 2, 1918: "In the bottoms it was 28 below....., and some places 30 below. I find a few live buds on hardy varieties (peaches) on top of the highest points, but not one can be found yet on the hillside or on lower hills."

On May 4, 1918, Mr. Snyder of Huron County wrote: "It is surprising to everyone to see so many peach blossoms coming out. It was thought that 25 degrees below zero would destroy every bud of even the hardiest varieties, but there seem to be some blossoms appearing on nearly every tree and some have nearly enough for a full crop. Apples and sour cherries seem to be but little injured. Sweet cherries nearly all killed; plums and pears about half destroyed. Raspberry canes badly killed, especially the black-caps."

Later in the summer of 1918 it was found that the injury was greater than had been expected, even along the lake. The older peach orchards were injured most, and many trees died even though blossoms appeared on them in the spring. The United States Department of Agriculture Report for August 3, 1918, stated: "The peach crop is quite short. The 'island' district will not have more than 10 per cent of a full crop—possibly less. A great many peach trees were killed by the cold last winter. The cherry crop was practically nothing and plums are scarce."

According to Secretary Cruickshank of the Ohio State Horticultural Society, "there was considerable winter injury to apple trees." Baldwin trees were reported to have large dead spots in the lower limbs and many limbs dead. It was noted that "Particularly in low spots in orchard land young trees often show injury in the crotches."

From the type of injury that occurred it seems that immaturity and root injury were associated with the low temperatures in causing so much damage. The temperatures remained relatively low so long that the lake failed to lessen the injury as much as it would have otherwise.

Mr. Selby of the Ohio Agricultural Experiment Station wrote in the Ohio Farmer of October 5, 1918: "In 1917 the whole season favored delay of matured growth.....a cold wet first half of summer was followed by heavy moisture and delayed ripening weather. The really cold winter found immature growths that naturally would freeze and kill. In the matter of fruit trees the growers can only take out the dead stumps—as is being done with possibly 1,000,000 bearing peach trees in Ottawa County—and begin over again."

There was much injury to apples in poorly drained locations and crotch injury was common, especially in the Stayman Winesap.

1935-36

The extensive destruction of fruit trees in January 1936 was due to a combination of conditions, some more prevalent in one section of the State, others more important in another region. A detailed account of several factors associated with the injury is given in this bulletin. Some of these were:

1. The short, wet growing season of 1935 which resulted in much immature growth
2. Frost early in October which caused many leaves to be injured before the optimum amount of carbohydrates was transferred into the stems and branches
3. The very rapid drop in temperature, as well as the low temperature of January 22 and 23, 1936. It has been shown, both in the laboratory and under field conditions of previous years, that a rapid drop is relatively more injurious to the upper parts of the tree than a prolonged cold.

REPORT OF INJURY IN WINTER OF 1935-36

METHODS USED IN THE SURVEY

Several methods were used in securing the information on the injury to trees during the winter of 1935-36. The four principal ones were:

1. An examination and study of typical orchards in all sections of the State during the spring and summer of 1936
2. A questionnaire sent to a large number of orchardists (about 500). A very high percentage of replies (206) was received. These replies were studied

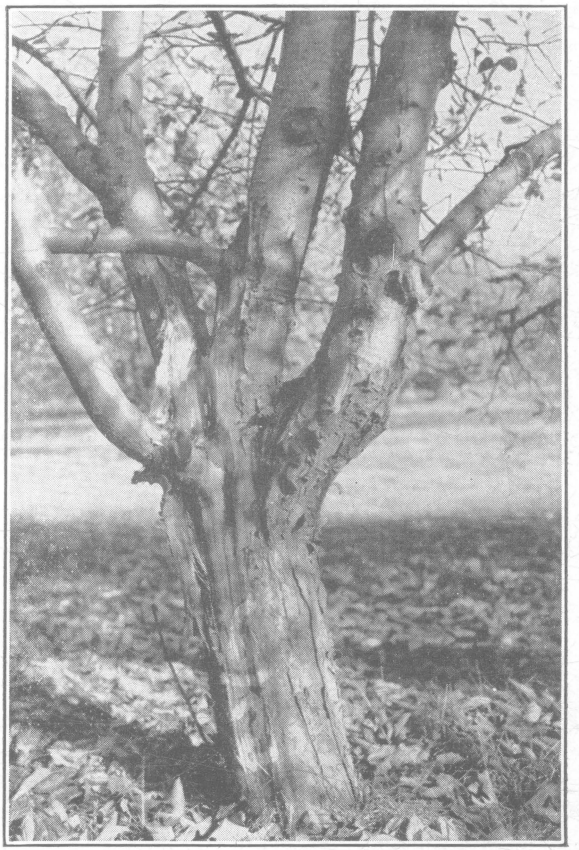

Fig. 2.—Stayman Winesap showing trunk and crotch injury commonly found following winter of 1935-36

Photographed in September 1936

and classified in detail. When specific questions arose from the nature of the replies, as often occurred, a further study was made of the orchard, either by examination or through further correspondence.

3. Statements of orchardists at the Experiment Station, State Horticultural Society Meetings, local fruit meetings, and elsewhere

4. Discussions and correspondence with members of the State Experiment Station and Extension Staffs.

The information secured in these studies was organized under the various factors which seemed to be associated with the injury. In some cases these factors were more closely associated with the type of injury and in others, with the severity of the injury. Because of the interrelation of many of these factors, it was often difficult and sometimes impossible to separate them.

A review of the literature on winter injury was helpful in interpreting the results in the light of previous research and observations.

THE SEVERITY OF THE INJURY

Probably 25 to 35 per cent of the mature apple trees in the State were injured during the winter of 1935-36 (Fig. 2). In some sections, such as the extreme western and south central portions, as high as 50 to 60 per cent were injured. In eastern Columbiana County and adjoining parts of Pennsylvania and West Virginia in some instances as high as 75 per cent were injured.

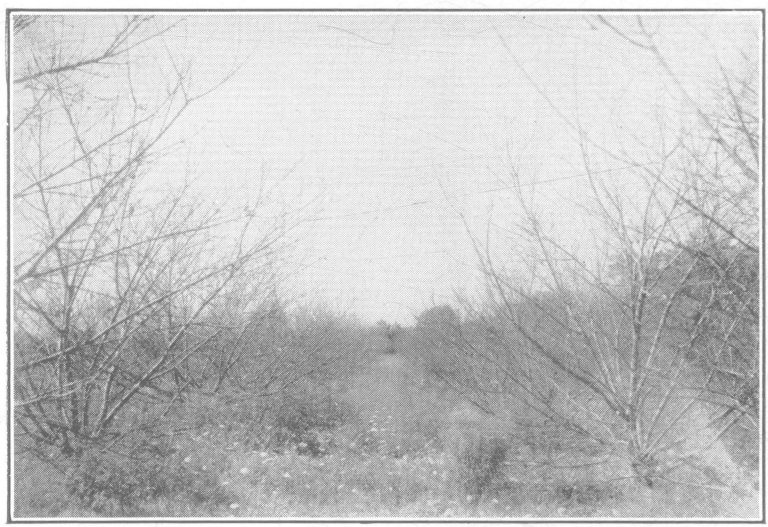

Fig. 3.—Peach orchard in southern Ohio (Ross County)

A common sight following severe winter of 1935-36
Photographed in August 1936

Pears, cherries, and plums were injured less, possibly because they are largely grown in regions which were affected less.

Peaches were most severely damaged. Probably between 60 and 75 per cent of the mature trees south of Columbus were destroyed (Fig. 3), and about 50 per cent of the mature ones north of there were killed or severely injured.

Many badly winter-injured apple trees set and matured a crop of fruit during the season of 1936, and much injury was not particularly noticeable to the casual observer until late in the summer when lighter, yellow-colored foliage began to appear. Many apple trees matured fruit when the cambium was dead and the bark loose entirely around the trunk of the tree. Many trees whose tops appeared to have survived well were found on closer examination to be injured. The injury was shown by discolored areas at the crown, by loose and cracked areas of bark on the trunk and limbs, also by discolored crotches and dead or injured lower limbs (Fig. 2). Several seasons will pass before the entire extent and effect of this injury will be realized.

RELATION OF MINIMUM WINTER TEMPERATURES TO SEVERITY OF INJURY

The minimum temperatures recorded during the critical period of January 22 to 24 in the counties which have official climatological data are shown in Figure 6. It may be noted that as a whole the lowest minimum temperatures occurred in the southern part of the State and the highest in the northern region along the lake. The severity of the injury to fruit trees follows the relative minimum temperatures only fairly well. As will be brought out later, many factors other than temperature were responsible for, or related to, the injury.

There were several days of relatively cold weather during the first part of October. This cold period began October 2 and lasted until October 9. On October 7 the temperature dropped to as low as 20° F. in some localities, and 25° F. was very common. This freezing temperature damaged the leaves and fruit causing considerable leaf dropping. On October 19 a very sudden dropping of fruit occurred, and October 19 and 20 many thousands of bushels of apples fell in northern and northeastern Ohio; much of the dropping was several days earlier in central and southern Ohio. This sudden dropping of the fruit was no doubt caused by the unseasonable cold temperatures of October 7 which disturbed the maturing processes of the trees. Considerable time during the fall is required for trees to mature and harden their wood[2] to a stage that can withstand even ordinary winter temperatures. Any condition which retards maturity causes the trees to be more subject to injury from low temperatures. The early October freezing temperatures were for this reason thought to be a contributing factor to the extensive winter injury that occurred later in January. Similar early frosts have, in other years, caused considerable damage. This was especially true in the fall of 1906-7 when on about the same date a slightly lower temperature prevailed throughout the State.

The remainder of October and November, 1935, mild temperatures prevailed. During the latter part of December, from December 21 to 31, the temperature reached a minimum of from —2 to —12° F. These temperatures occurred gradually, however, and were not low enough to cause injury in most of the State.

The first half of January was very mild; as high as 62° F. was recorded in southern Ohio, and much of the time temperatures above freezing prevailed. Following this mild period, however, the weather suddenly changed. On January 22 the temperature dropped very rapidly from above freezing to a minimum of from —10 to —20° F., and this severe temperature was accompanied by strong southwest winds gradually shifting to the northwest. A drop in tem-

[2]The word *wood*, as used in this bulletin, includes the entire stem rather than the xylem only.

perature of from 40 to 50° F. in 10 hours was not uncommon. On the next 2 days the temperatures dropped even lower in some localities to a minimum of from —10 to —30° F. in some parts of the State, and a range of from —14 to —20° F. was a common occurrence. After these minima were reached, the temperature remained low (—4 to —12° F.) for about a week.

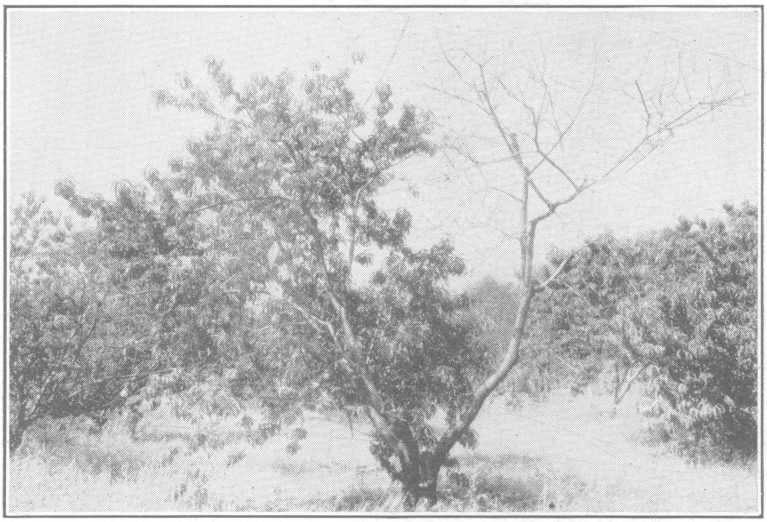

Fig. 4.—Mature peach trees typical of type of killing in northwestern Ohio, especially in Sandusky and Ottawa Counties

Many fruit buds, even on Elbertas, were not destroyed, even though trunks, crotches, and many branches were completely killed.

The rapidity of temperature drop, the intensity of the cold itself, and the immaturity of wood in a great many orchards were the factors directly responsible for the severe winter injury to fruit trees (Fig. 4). As previously described, the rapid drop in temperature on January 1, 1864, seemed to be responsible for much damage that severe winter. That strong winds and possibly bright sunshine along with the drop in temperature also added to the damage in January 1936 is shown by the fact that much of the trunk damage was on the southwest, west, and northwest sides of the trees and was often severe in locations exposed most to the wind. It is true, however, that other factors, such as poor soil drainage and immaturity of trees, resulted in much damage in "protected" locations.

Apple trees came through the winter of 1935-36 fairly well where the temperatures did not fall below —10° F., but temperatures of —14° F. or below usually were accompanied by injury of some degree or nature. After the very low temperatures of January no other extremely low temperatures occurred during the remainder of the winter.

RELATION OF CULTURAL SYSTEMS TO INJURY

The cultural treatment associated with the most winter injury during the winter of 1935-36 varies somewhat, since other factors, such as soil type, site, and fertilization, were often interrelated.

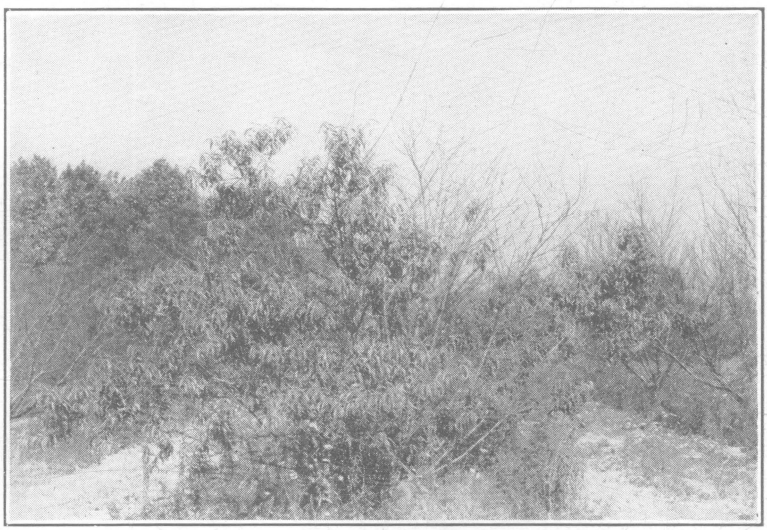

Fig. 5.—Peach orchard severely injured (Ross County)

The photograph shows stock or a branch of the seedling which was much hardier than the budded variety (Elberta).

One of the most striking comparisons observed in cultural practices was between winter injury to apple trees in mulch and injury to those in sod without mulch. In one instance (Geauga County) Wealthy trees planted in 1918 which had been given the two distinct cultural treatments were compared. The alternate rows, to be used as permanents, had been mulched every year for the past 5 years with manure and straw. The remaining trees, fillers, had not been mulched, but had been allowed to remain in sod only. Almost without exception the bark was entirely loose around the trunks of the fillers and in good condition around the permanents (Fig. 7). The fruit matured on the injured trees even though none of the bark remained alive around the trunk and the leaves became yellow just before the crop was harvested.

In an orchard near Clyde, Ohio, a somewhat similar result was found. Wealthy and Baldwin trees in straw mulch (mulched during the late fall and winter of 1935) were in good condition. In contrast to this, the foliage of many unmulched trees was yellowed and the trunks were injured in almost all cases where other factors, such as soil and site, were similar. These trees were observed in August, and the injury had not been evident before then.

A somewhat different situation was seen at Berlin Heights, Erie County. The trees there were very old Baldwins that had been mulched with straw for several years. It was noticed that the bark was very slippery on the mulched

trees at the time of pruning. The outer portion of the bark began to slough off in the spring and continued to do so during the summer. Although this was probably a type of winter injury, the trees seemed to be in good condition otherwise. It should be emphasized that only the outer portion of the bark was loosening and that the inner bark was alive.

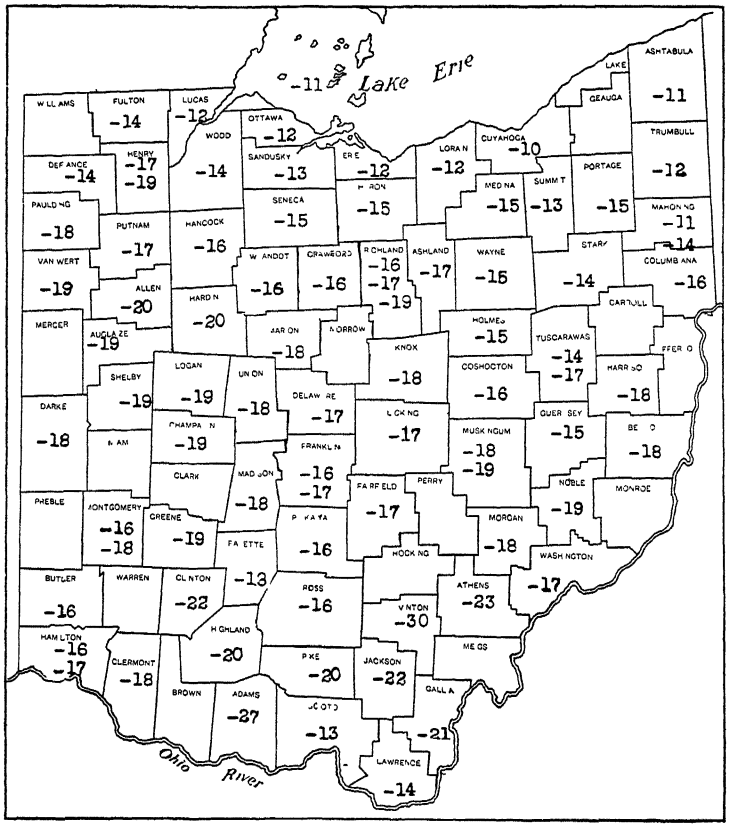

Fig. 6.—Maximum and minimum temperatures (in degrees F.) reached in various counties during winter of 1935-36 (occurred January 22-24)

Note that the lowest recorded was in Vinton County (—30° F.) and that the highest official minimum was in Cuyahoga County (—10° F.). Where minimum temperatures recorded in a county were different, they are given also. From United States Department of Agriculture Weather Bureau Climatological Data: Ohio Section, January 1936

The value of mulch materials around trees is not new. In surveys following other severe winters it was often found that trees survived better in mulch than in cultivation. This was especially noticeable in Ottawa County following the severe winter of 1903-4, and also throughout northern Ohio following that of 1917-18.

Orchards in which there was a vigorous cover of weeds or cover crops during the winter of 1935-36 were not injured as severely as those in a perfectly clean condition. This was especially true of northern and northwestern Ohio.

Fig. 7.—Wealthy apple trees planted in 1918

The row on left (filler) in sod only; that on the right mulched with straw and manure for about 5 years. Note the severe winter injury to trunks on left and no injury to trees at right. Photographed August 13, 1936, in Geauga County, Ohio

It was extremely difficult to determine the reason or reasons for the striking differences observed between certain mulched, sodded, and cultivated orchards. Since root examinations showed that apparently the roots were not injured, it was probably not a case of direct killing of roots in the sod or in cultivation. Since the effect of the mulch was evident even if it had been present only since the late fall or early winter of 1935, it was not altogether an effect of the mulch over a period of several years. Several explanations have been given, but probably the most likely ones are:

1. There was a more constant moisture supply under mulch during the winter, spring, and summer of 1936.

2. The mulch protected the soil against a great depth of freezing. It is well known that the soil does not freeze to as great a depth under straw as under cultivation. The protection of the mulch prevented freezing of the free water to such a great depth as otherwise and made it possible for more roots to be active in absorption of water. Doubtless this explanation at least partly accounts for the difference in injury often found between trees in cultivation and trees in sod or mulch.

In Columbiana County in several cases the breaking up or cultivation of sod orchards during the spring or summer resulted in more injury the following winter than had occurred before. In most of these cases a weed hog or some

other heavy cultivating tool had been used to tear up the sod, and several cultivations had been given. As a result, the trees had grown more vigorously during the summer and fall of 1935. In one instance cultivation was carried on as a means of decreasing the infestation of apple flea weevil, and winter injury occurred where the trees were so treated. Wherever increased growth was stimulated by cultivation and breaking up of the sod, especially if the growth continued late in the season, winter injury was severe. Injury was greatest where the overwinter soil covering was the least.

Invariably where other conditions were alike there was less injury in sod orchards than in those under some sort of cultivation. Most orchards in grass sod were growing less rapidly than those in cultivation and varied from normal to very little growth. Winter injury usually decreased as the growth rate decreased until trees showed actual weakness. Trees that grew slowly and failed to bear fruit matured their growth early and showed relatively little winter injury. Trees making a normal or better than normal growth in sod were more apt to show some winter injury than slower growing trees.

Another notable example of a cultural situation associated with winter injury was found where an attempt was being made to maintain trees in a legume sod. This was especially noticeable in a West Virginia orchard near the Ohio border where 2,000 or more Wealthy and York trees were killed or badly injured. These trees were in vigorous growing condition and capable of bearing heavy crops owing to the breaking up and cultivation of the ground several seasons previous when starting the legumes. The conditions favorable for growth of legumes also stimulated tree growth and hence more likelihood of winter injury. Trees in permanent legume and alfalfa sod of long standing were slower of growth and less injured, as were the grass sod orchards.

Several examples were noted where trees in sod in very favorable locations for growth were badly winter-injured. A number of trees were severely injured in a particular area in an orchard in Jefferson County. It was found that this part of the orchard had formerly been a barnyard and that the ground on which the trees were growing was exceedingly fertile; hence the trees were growing vigorously. Wherever any cultural condition tended toward excessive growth and late maturity of wood, winter injury was most severe.

In Fairfield County there was an example of 10-year-old peach trees grown under two systems of culture: (a) in sweet clover sod continually and (b) in cultivation for 8 years then seeded to a sod in 1934. The block grown in the clover sod was injured least by the winter. In most cases, where comparisons could be made, it was found that all fruits were more severely injured when grown under clean cultivation. This was true in comparison with the mulch system or with a good system of cover crops.

Perhaps the reason that such striking results of different systems of culture were not obtained in some sections of southern Ohio was that a very heavy covering of snow protected the ground to some depth.

EFFECT OF FERTILIZATION ON WINTER INJURY

No direct relation could be traced in the orchards examined between the fertilization practices and winter injury. In general, however, the old orchards which had been fertilized according to the usual custom[3] and not heavily pruned were in better condition than those treated otherwise.

[3]This is ¼ pound of nitrate of soda (or equivalent amount of nitrogen in other carriers) to each year of a tree's age.

It was also noted in Jefferson and Hamilton Counties that the trees grown in the most fertile soil suffered most. Moderate fertility seemed most favorable for recovery. Even trees which grew poorly sometimes survived relatively well, especially where crops of fruit had been small and the trees had not been weakened from some other cause.

It has been suggested that fall fertilization, especially with a nitrogenous fertilizer, was responsible for some winter injury. This factor was checked in various parts of Ohio where comparisons could be made. In no case could the use of a nitrogenous fertilizer in the previous late fall or winter be directly associated with the injury in 1935-36. There was some indication, however, that nitrogen applied during the summer, or early enough in the fall to accelerate growth, was conducive to more widespread injury due to lack of maturity. These results are in agreement with Anthony, Sudds, and Clarke (2) who conclude: "Time and amount of fertilizer applications seem to have influenced the degree of injury only when they have increased or decreased the maturity of the trees. Source of fertilizer does not appear to have been a factor in modifying tree injury." Bradford and Cardinell (4), after a study of a large number of winters in Michigan, state: "Heavy manuring in conjunction with cultivation has received unfavorable mention on numerous occasions, because of the late growth thereby induced, and the extensive damage resulting." The same may well be stated regarding injury in Ohio, including that of the winter of 1935-36.

There was opportunity to observe two orchards at the Experiment Station (Wooster) which had been treated somewhat differently. Each orchard consisted of 5 acres, and both were planted in 1922. The only variety common to both was Stayman Winesap, a variety which showed considerable susceptibility to winter injury in most sections of the State.

In the one orchard (K) about half the trees were treated in the autumn with calcium cyanamide; part of the remainder was treated with this material in the spring. The others were either untreated or fertilized with sulfate of ammonia. Treatments had been in progress for 5 years before the severe winter of 1935-36. The other orchard (J) was treated entirely in the spring with nitrate of soda as the only nitrogen carrier. One row (19 trees) received phosphorus in addition; another potash in addition; one row a complete fertilizer; and one was untreated. These treatments had been in force for 8 years before the cold winter of 1935-36.

Orchard K (the one where Cyanamid was used in the fall) was injured much less than orchard J, which had a considerable amount of body, branch, and crotch injury in all varieties (Stayman Winesap, Baldwin, and Wealthy). Apparently neither the fertilizer materials in themselves nor the time of application was responsible for the injury. Possibly the use of a weed hog during the summer in orchard J may have stimulated the trees, or the lack of proper maturity may have been due to some other cause.

This experience would prompt the suggestion that circumstantial evidence should be carefully examined before conclusions are drawn. If the usual fertilizer treatments, either in spring or fall, are directly responsible for winter injury, the evidence did not appear in these studies.

EFFECT OF CERTAIN SOIL CONDITIONS ON WINTER INJURY

Soil drainage played an important role in the winter injury of 1935-36, both in the injury during the winter and in the death of trees throughout the following summer (Fig. 8). In all sections of the State the trees which were on poorly drained soil were most severely injured. Some of the trees had apparently been in good condition before the severe winter, but in most instances they had evidently already been weakened.

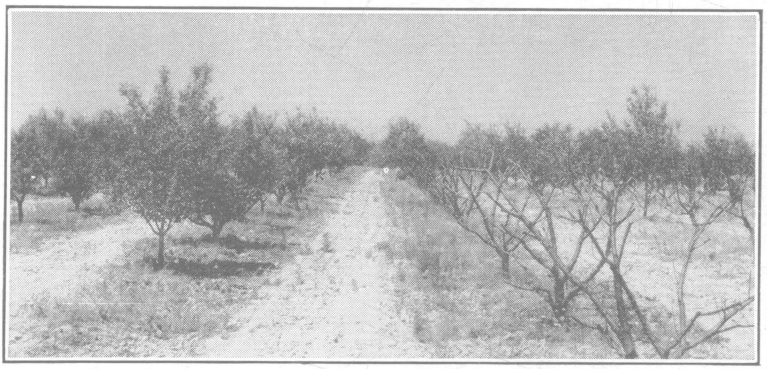

Fig. 8.—Peach trees dehorned just after growth began

None of those at right survived; however, the section of the orchard there is poorly drained. Peach trees at left, where drainage is more favorable, survived fairly well. Photographed in Clark County, Ohio

Several peach trees were destroyed in the variety orchard at the Station because of the drainage condition. Those most severely damaged were growing in Trumbull silt loam. Trees near by in Canfield and Wooster silt loams survived much better.

Trees in shallow soils or in soils in which for any reason the roots remained relatively near the surface seemed to be in poorer condition following the winter than those rooting deeper. This was perhaps most often seen in peach orchards; however, many apple trees also suffered as a result of shallow rooting even though there was little direct killing of the roots.

A great many trees, especially in the southern and southwestern parts of the State, would possibly have survived following the winter had it not been for the severe drouth and heat during the early summer of 1936. In many cases young trees set out late in the spring soon died. The damage in some localities noted during the late summer and fall of 1936 was not due entirely to the winter, but was due to a combination of previous winter injury and drouth damage.

In general, any soil condition which greatly limited the depth and distribution of roots or caused the trees to grow vigorously until relatively late in 1935 tended to cause the trees to be more susceptible to winter injury.

RELATION OF AGE OF TREES TO WINTER INJURY

Almost invariably the amount of winter injury varied directly with the age of the trees when other factors were similar.

The injury to apple trees was most severe on bearing trees over 15 years of age. Some exceptions were young trees that had been heavily fertilized with nitrogen very late in the season, and young trees heavily pruned before the minimum temperature in January.

In an orchard at Clyde (Sandusky County) plum trees which had borne a crop survived better than those which had not reached bearing age.

Young Stanley, Albion, and Grand Duke plums set in the spring of 1935 in another orchard only a short distance away were injured more severely than more mature trees of Grand Duke and other common varieties.

In an orchard in Sandusky County, Rochester peach trees planted in 1935 were more severely injured than those planted in 1934 (Fig. 9).

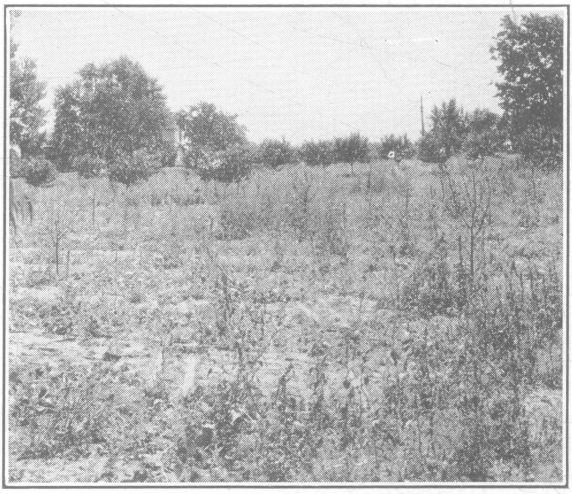

Fig. 9.—The peach orchard in the foreground showing severe injury was planted in 1935 (see also Fig. 10); that in background with little injury was planted in 1934.

Photographed in Sandusky County where this type of injury was most common

Another interesting observation was made in the same orchard of Rochesters planted in 1935. One row of peach trees had been planted near a row of asparagus on the edge of the planting (Fig. 10). The row near the asparagus was not cultivated during the season of 1935 as much as were the others. Little injury occurred in this outside row, probably because of the more mature growth resulting from lack of cultivation and lack of water and nitrogen, which the asparagus used in competition with the trees.

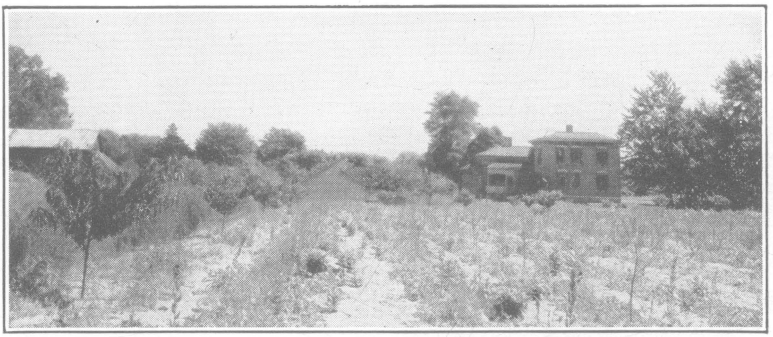

Fig. 10.—Rochester peach trees planted in spring of 1935

Those on right in photograph were in clean cultivation during growing season of 1935. The row on the extreme left was cultivated less and also was only a few feet from the row of asparagus (as shown in photograph). Note difference in number of dead trees following winter of 1935-36. (Clyde, Ohio, Sandusky County)

At the Experiment Station, as well as in most other parts of the State, trees planted in 1935 survived at least as well as those of any other age. A study of the literature shows that usually older trees have been injured most severely, although in a few instances the reverse has been true. In a few cases young trees seemed to be less mature than older ones and were more susceptible to injury. However, probably because of the greater proportion of foliage to wood, younger trees are usually more mature (from this standpoint) and hence, less susceptible.

SOME EFFECTS OF TIME AND SEVERITY OF PRUNING ON THE INJURY

Fruit trees pruned, even moderately, before the severe temperatures of January were usually injured more than those pruned after this or not pruned at all.

Where pruning had been most severe winter injury was worst. Many top-grafted trees severely pruned to eliminate the undesired varieties after grafting and trees pruned severely in the operation of grafting in the spring of 1935 were either entirely killed or severely injured during the winter of 1935-36. That the injury was brought about by pruning was strikingly illustrated in an orchard in Columbiana County. In this orchard a number of 10-year-old trees had been top-grafted in the spring of 1934. In December 1935, half of one row of trees was pruned to eliminate partially the wood of the undesired variety and allow the grafts to grow. The remainder of these trees was not pruned. All the pruned trees were winter-injured so badly that they died during the summer, but the unpruned trees suffered practically no injury (Fig. 11, A and B).

In the same vicinity Baldwin apple trees 40 years of age that had been pruned annually for several years and pruned again before January were badly winter-injured. The injury in this orchard was estimated at 75 per cent. In a near-by orchard of the same age and variety but unpruned for the last three seasons the injury was very slight.

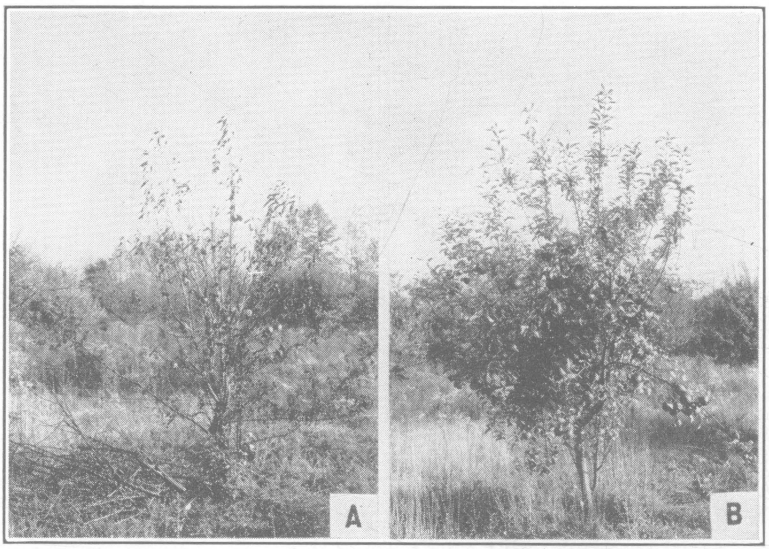

Fig. 11.—A, young apple tree top-grafted in 1934 and undesired branches removed in December 1935; B, same treatment as A except that no branches were removed after top-working. A failed to survive severe winter. B was not injured.

Although, as previously stated, young trees were usually injured least, they showed the disastrous effects of pruning even more than older trees. Many young trees showed injured areas around and just below the wound left by the removal of the limb. This injured area many times extended a considerable distance down the trunk (Fig. 12). In more severe cases the crotches and the entire trunk were injured near the stubs where limbs had been removed in pruning.

Peach trees at the Experiment Station which were either given a moderately heavy pruning or dehorned in February were more severely injured than those pruned later or not pruned. In an orchard near Canton, Stark County, 7-year-old peach trees headed to about 4½ feet in height just after the leaves appeared survived very well (Fig. 13). These, as well as other observations, indicate that young peach trees may be pruned more heavily following a severe winter than older ones.

In northwestern Ohio mature peach trees which had been pruned heavily 2 years before (1934) were observed in comparison with trees near by which had not been so pruned (Fig. 14).

Apparently in no other winter has the value of pruning after the most severe temperatures are over been demonstrated as definitely as in that of 1935-36. At least there is little in the literature indicating such definite responses of all fruits in this regard. Following the winter of 1935-36 the results were so definite that many large orchardists stated that they would in the future prune all fruit trees only after they felt that the severe temperatures were over for the winter.

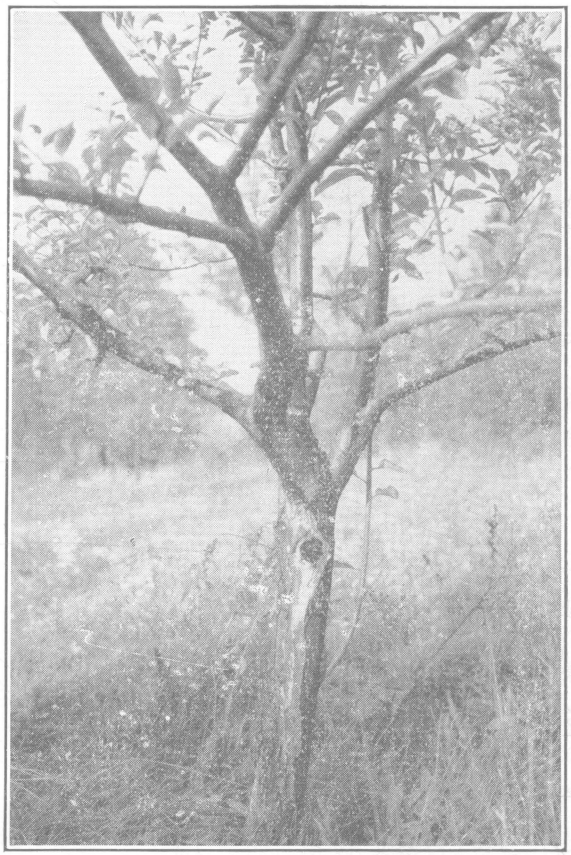

Fig. 12.—Type of injury often found below and around the pruning wound on young apple trees which were pruned in November and December 1935

Photographed in Columbiana County in September 1936

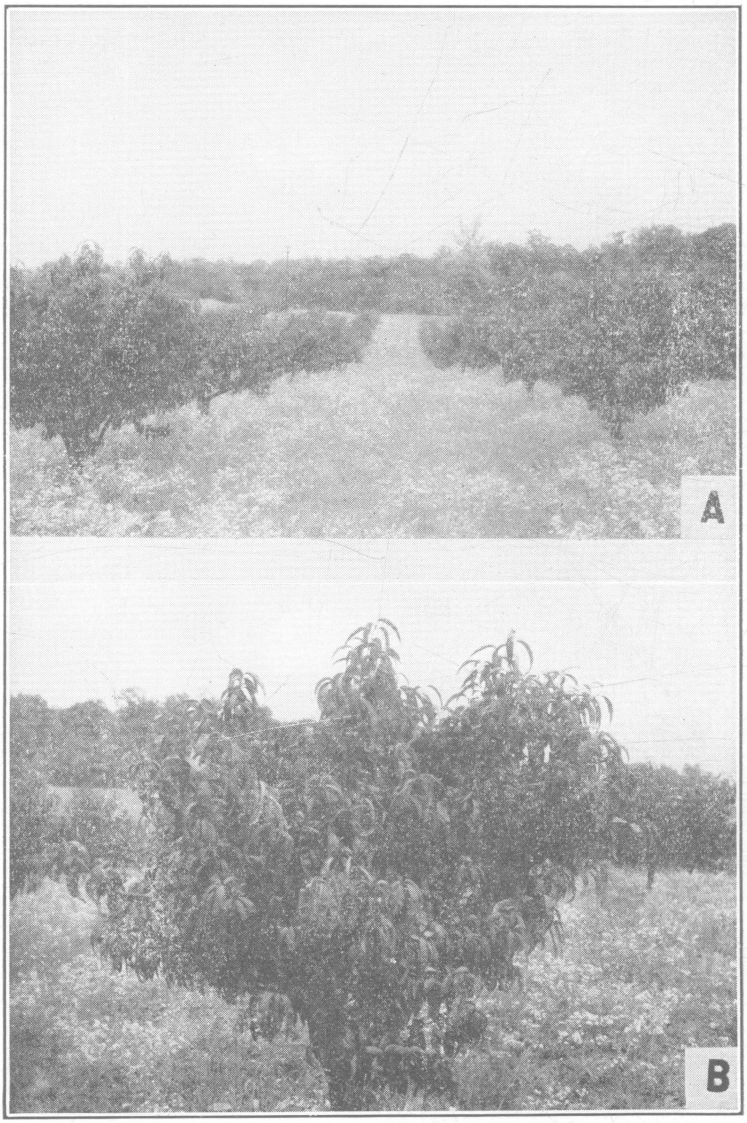

Fig. 13.—Peach trees about 7 years of age pruned to approximately 4½ feet in height just after growth began in 1936

These trees survived the previous winter very well. **A**, general view of the orchard; B, more detailed view of a typical tree. Photographed in Stark County, Ohio, on October 6, 1936

Fig. 14.—Illustration of the effect of heavy pruning on winter injury of mature Elberta peach trees

A, pruned heavily in the spring of 1934. Usually not more than one or two branches remained alive on such trees in this orchard following the winter of 1935-36. B, pruned very little in 1934. A few dead branches in these trees were found which do not appear in this illustration. Photographed near Clyde, Ohio, in August 1936

Aside from the results of the winter of 1935-36, previous observations by several workers including Beach (3) and Bradford and Cardinell (4) had shown that pruning of peach trees in early winter or before the most severe temperatures caused them to be particularly susceptible to injury. Burkholder (5) observed considerable injury to 10-year-old Jonathan and 10- and 14-year-old Stayman Winesap trees following pruning in December 1935 at Lafayette, Indiana. He states in his report that "The amount of injury on both varieties was in direct proportion to the severity of the pruning." Burkholder's results are in accord with those observed in Ohio following the winter of 1935-36, although all commercial varieties seemed to be affected to some extent. In this connection, however, Bradford and Cardinell (4) state: "In the apple, there is little or no evidence of serious consequence of winter pruning on trees of mature age."

Heavy pruning or dehorning of peach trees immediately following a severe winter has also been disastrous, as noted by several workers including Beach (3) and Gunderson (10). A moderate pruning after growth had begun seemed most satisfactory.

One of the striking observations of the winter injury survey in 1936 was that in all sections of the State early pruning, especially of young trees, before the minimum temperatures of January, was accompanied by increased winter injury. As a result of these findings, fall or early winter pruning of fruit trees

must be considered a hazard so far as winter injury itself is concerned. The most favorable time for pruning to avoid danger of injury seems to be spring or late winter after severe weather is over. In the case of winter-injured trees, pruning should be done after growth has started, as this allows the pruner to see just how much live wood remains and where to cut in order to prune out the dead or badly injured wood.

RELATION OF PRECEDING CROP TO WINTER INJURY

There seems to be no doubt that the most severe injury followed heavy crops in 1935 when other conditions were the same. Trees that bear heavy crops of fruit draw heavily on their food and nutrient supply. This seems to cause lack of or delayed maturity of the wood and increases the likelihood of winter injury.

Varieties that have a tendency to overbear to the extent of weakening the trees seemed to be the most severely winter-injured. Wagener and Hubbardston are examples of apple varieties that under normal conditions bear exceedingly heavy crops every other year. Wagener is such a heavy alternate bearer that it is sometimes said to "bear itself to death". Such varieties were almost always found to be rather severely winter-injured in January 1936 if they had borne a heavy crop in 1935. Grimes Golden was a notable exception, being especially free from winter injury in the northern half of the State, yet in many cases having borne a heavy crop in 1935. Wealthy, though usually considered hardy, was in most cases severely injured where it had borne heavy previous crops.

It was noted that peach trees which bore a full crop and were not thinned in 1935 were most severely injured when other factors were similar. This was especially noticeable in a block of Elbertas at the Experiment Station which had been used for thinning experiments.

In a report on the winter injury of Baldwin apple trees following the winter of 1933-34, Collison and Harlan (7) state: "There was a significant tendency for high yields of the previous season to accompany extensive winter injury." They state further that "This tendency was the reverse, however, when 4 years' yields were considered." Other investigators including Chandler (6), Anthony et al. (2), and Tingley and Potter (17) have also recorded definite indications that heavy crops preceding a severe winter cause the trees to be more susceptible to injury.

INSECTS, DISEASES, AND DROUTH IN RELATION TO WINTER INJURY

Wherever trees had been weakened, whatever the cause, they were subject to more winter injury than unweakened ones.

Apple trees severely infected with apple scab in 1935, defoliated by too caustic sprays, or injured by apple flea weevil, red mite, or other insects or diseases were often severely injured; whereas others more free from these types of damage survived the cold temperatures well.

Many apple orchards in southeastern Ohio injured by the drouth of former years and then attacked by "apple measles" and further weakened, were completely killed by the winter temperatures of 1935-36. This combination of drouth and disease devitalized the trees so that they were more susceptible to the low temperatures, and it has destroyed thousands of formerly productive apple trees in southern and southeastern Ohio.

Cherry trees defoliated by leaf spot or some other condition late in the summer of 1935 were injured more during the following winter than trees which retained their leaves longer. The same was true of peaches, plums, and other trees.

Peach trees weakened by borers or other insects were also more subject to winter injury.

These interrelations of the results of insect and disease injuries and susceptibility to winter injury have long been noted by growers and investigators.

SUSCEPTIBILITY OF VARIETIES TO WINTER INJURY IN 1935-36

Apples.—The results of the survey following the winter of 1935-36 showed that the relative hardiness of varieties, especially of apples, was variable in the State as a whole. Some of this variation was eliminated by dividing the State into six geographical divisions (Fig. 15). Even then the relative hardiness was not consistent, and any classification given could not be exact for all orchards in a given division.

Fig. 15.—Map of Ohio showing various divisions into which it was divided in order to classify apple varieties with regard to their relative hardiness of wood during the winter of 1935-36

It is probable that the short growing season in 1935 and the early frost (October 4 and 5) which caused injury to the leaves in northern Ohio that year, were responsible for some of the varietal inconsistencies. Also, it should be noted that many trees were weakened by the severe winter of 1933-34, especially in northeastern Ohio. Of course, certain apple varieties are more satisfactorily grown in some parts of the State than in others. It has been stated that when a variety is grown "out of its region" it is more responsive to adverse conditions. Perhaps this is true of some of the varieties, yet Rome Beauty (characteristic of southern Ohio) was injured less in the northern part of the State.

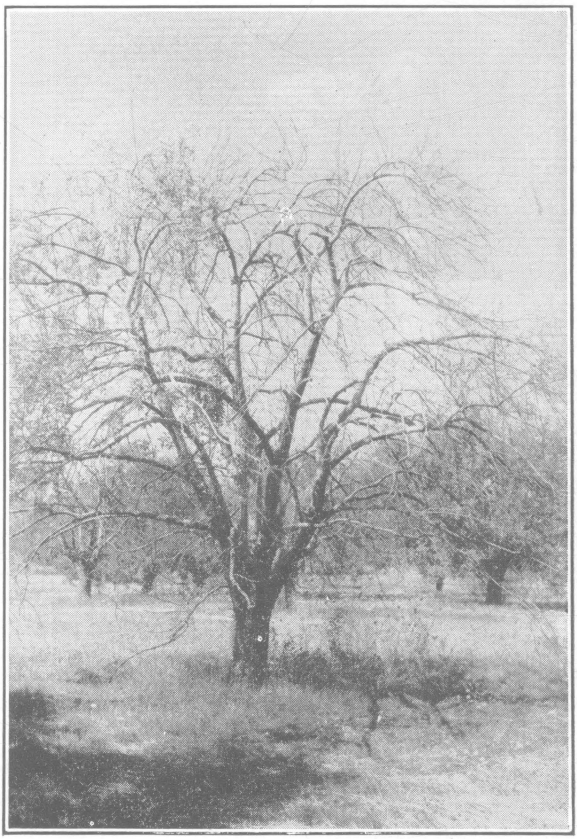

Fig. 16.—A common type of injury of old Baldwin apple trees in southern Ohio following winter of 1935-36

Note dead lower branches and other branches throughout the tree. Photographed in Ross County

Growth characteristics of apple varieties differ. It seems likely that because of these differences some varieties were winter-injured more than others (Fig. 16). Varieties, as well as trees, having sharp crotches were apt to show more crotch injury than those branching at a wider angle. Delicious was

a good example of this. Growth seemed less mature in sharp-angled crotches than in wide ones. Horsfall (11) explains this greater susceptibility of crotches to injury by pointing out that most conduction takes place in the sides and lower part of the scaffold limbs, and that a relatively small amount of the substances elaborated in the leaves moves into and through the crotches. He states that "Apparently resistance of the wider crotches to winter injury is a result of slower growth rate."

The following classification of varieties is based primarily on relative wood hardiness in the winter of 1935-36; however, where the classification of a variety is unusual a note to that effect is added.

Northwestern Division:

MOST HARDY	LEAST HARDY
Oldenburg	Baldwin
McIntosh	Wagener
Yellow Transparent	Delicious
Rome Beauty	Tompkins King
Northern Spy	York Imperial
Cortland	Stayman Winesap
	Wealthy[4]
	Winter Banana

Northeastern Division:

MOST HARDY	LEAST HARDY
Oldenburg	Baldwin
Gano	Wagener
McIntosh	Wealthy[4]
Grimes Golden	Hubbardston
Maiden Blush	Tompkins King
Cortland	Delicious
Rome Beauty	Winter Banana
Willow Twig	York Imperial
Bentley Sweet	Jonathan
Ohio Nonpareil	Stayman Winesap
	Stark
	Golden Delicious
	Opalescent

In some orchards in the Northeastern Division Winter Banana, York Imperial, Delicious, Jonathan, Stayman Winesap, and Stark were badly injured; in others they were injured very little. Rome Beauty and Grimes Golden, although considered by some to be out of their natural growing region in northeastern Ohio, were consistently hardy.

Central Division:

MOST HARDY	LEAST HARDY
Yellow Transparent	Baldwin
Oldenburg	Hubbardston
Maiden Blush	Stayman Winesap
Northern Spy	Wagener
Rhode Island Greening	Ontario
McIntosh	Rambo
Winter Banana	Jonathan
Cortland	Delicious
Grimes Golden	Tompkins King

[4]Wealthy was severely injured in the Northwestern and Northeastern Divisions in 1935-36, although it is considered relatively hardy in Ohio.

Some varieties which were the most hardy in some orchards and the least hardy in others, depending on a number of conditions, such as previous crop and age of trees, were: Grimes Golden, Rome Beauty, Wealthy, and Jonathan. The Northern Spy also varied somewhat, but was relatively hardy in the Central Division.

East Central Division:

MOST HARDY	LEAST HARDY
Winter Banana	Baldwin
Wealthy	Rome Beauty
Oldenburg	Golden Delicious
Yellow Transparent	Yellow Bellflower
McIntosh	Delicious[5]
Stayman Winesap	Jonathan
Grimes Golden	Opalescent
	Tompkins King

In the East Central Division of the State the Red Delicious seemed more hardy than the Golden Delicious. In some orchards the Stayman Winesap was one of the most hardy varieties, but in others it was one of the most injured. A satisfactory reason for this could not always be found. Grimes Golden and Jonathan were also inconsistent. The Rhode Island Greening seemed relatively hardy in the East Central Division in 1935-36, although it could hardly be classified as a hardy variety even here.

Southwestern Division:

MOST HARDY	LEAST HARDY
Winesap	Baldwin
Cortland	Rome Beauty
Maiden Blush	Stayman Winesap
Arkansas	Ben Davis
Wolf River	Rambo
Gano	Golden Delicious
Delicious	Tompkins King
Yellow Transparent	Ensee

Grimes Golden, Jonathan, York Imperial, Wealthy, and Northern Spy were somewhat variable in hardiness. In this Division, as in the East Central, the Rhode Island Greening seemed relatively hardy in 1935-36.

Southeastern Division:

MOST HARDY	LEAST HARDY
Winesap	Baldwin
Yellow Transparent	Rome Beauty
Cortland	Stayman Winesap
Maiden Blush	Jonathan
McIntosh	Delicious
Grimes Golden	Wealthy[6]
Northern Spy	York Imperial
	Tompkins King
	Ensee

[5]Delicious was severely injured in the East Central Division in 1935-36, although it is considered relatively hardy in Ohio.

[6]Wealthy was severely injured in the Southeastern Division in 1935-36, although it is usually considered relatively hardy in Ohio.

In this Southeastern Division all commercial varieties were injured more or less by the severe winter of 1935-36, and no variety entirely escaped injury in all orchards. Although the Northern Spy does not usually rank with the most hardy varieties, it seemed relatively hardy that year.

Considering the State as a whole in 1936, certain varieties seemed most hardy; others were least hardy; and there was an intermediate group of varieties which in some cases were relatively hardy and in others were injured severely.

MOST HARDY	INTERMEDIATE	LEAST HARDY
McIntosh	Rome Beauty	Baldwin
Cortland	Stayman Winesap	Wagener
Northern Spy	Delicious	Hubbardston
Grimes Golden	Golden Delicious	Tompkins King
Oldenburg	Jonathan	Ben Davis
Yellow Transparent	Winter Banana	Gravenstein
Maiden Blush	Ensee	
Winesap	Wealthy	
Willow Twig	York Imperial	
Bentley Sweet	Rhode Island Greening	

There were several types of injury that were somewhat characteristic of varieties. There were exceptions, but the usual types were:

Wealthy—loosening of bark around trunk and sometimes around branches; also crotch injury, especially in northern Ohio
Baldwin—lower limbs most injured; then crotch and crown injuries
Yellow Transparent—spots and strips of injured bark on larger limbs; then trunk and crotch injury
Tompkins King—crown, some crotch injury
Rome Beauty—large limbs and trunk in southern Ohio and crotches in northern Ohio
Jonathan—trunk injury and fruit buds
Ben Davis—crotch and crown injuries
McIntosh—spots and strips of injured bark on trunk
York Imperial—crown and trunk injury
Northern Spy—crotch injury
Rhode Island Greening—lower branches and trunk

Peaches.—There was some variation in the relative hardiness of the wood of peach varieties in individual orchards during the winter of 1935-36, but as a whole their wood hardiness may be classified for the State. Such a grouping is given here.

MOST HARDY (IN WOOD)	LEAST HARDY (IN WOOD)
Rochester	J. H. Hale
Carman	Wilma
Champion	South Haven
Lemon Free	Hiley
Banner	Early Elberta
Salberta	Heath Cling
Krummel	Kalamazoo
Smock	
Brackett	

Plums.—The relative hardiness of wood of plum varieties may be classified in a general way for the entire State.

MOST HARDY (IN WOOD)	LEAST HARDY (IN WOOD)
The Damson group	Reine Claude
The American group	Lombard
The Japanese group	McLaughlin
Gueii	Palatine
Austrian Prune	Hall
Italian Prune	Pearl
German Prune	
Stanley Prune	

Although this bulletin deals primarily with wood hardiness, the following observations on fruit bud hardiness in plums may be of value here.

At the Ohio Experiment Station a full crop of plums was produced on the following varieties in 1936: Nixie, Freestone Goose, Crittenden Damson, and French Damson. Several Damson varieties produced a crop which may be considered fair. These were Prune Damson, Kelso, Deck's, Riley, and Finch. The White and Sweet Damsons were most tender in bud of the Damsons. Plums producing a light bloom and few fruits, in no case amounting to more than a peck per tree, were Pond, Standard Prune, Yellow Egg, Surprise, Pacific, Lombard, Stanley, Imperial Epineuse, and Italian Prune. Some common varieties producing no blooms whatever were Reine Claude, Burbank, Clyman, Hall, French Prune, Arch Duke, Agen, Imperial Gage, Gueii, and General Hand.

Cherries.—There was considerable injury to the wood of sweet and duke cherries, especially in the southern part of Ohio, during the winter of 1935-36. In general, however, the cherry region is located in the northern part of the State, where the least damage occurred. For this reason, and because of a lack of sufficient varieties under similar conditions, no definite results regarding relative susceptibility of varieties to wood injury could be established.

Only a light crop on a few varieties of sweet cherries was produced in northern Ohio in 1936 because of the destruction of fruit buds during the previous winter. The varieties which seemed most hardy in bud were Bing, Yellow Spanish, and Governor Wood. Those most severely injured in fruit bud were Lambert, Windsor, and Black Tartarian. All fruit buds of the 22 sweet cherry varieties grown at the Experiment Station were destroyed during January 1936 at —15° F. Very little wood injury occurred, however, on any varieties except those already growing poorly.

There was little injury to the wood of the sour cherries in Ohio as a whole during the winter of 1935-36, but this was mainly due to their being grown largely in northern Ohio where least injury occurred. None of the varieties were severely injured at the Experiment Station. A few of the trees which were already weak were injured slightly, but there seemed to be no relationship between injury and variety.

The following sour cherries seemed most hardy in fruit bud: English Morello, Chase, Wragg, and Ostheim (all Morello type). The fruit buds of the following varieties growing in the same localities were often found injured: Montmorency, Homer, Olivet, Early Richmond, and Baldwin.

Pears.—As mentioned previously, it was difficult to obtain definite results of the relative wood hardiness of pear varieties in 1936. The classification given here is necessarily somewhat general.

MOST HARDY	LEAST HARDY
Pulteney	Bartlett
Phelps	Wilder Early
Kieffer	Beurré Bosc
Conference	Angouleme (Duchess)
Flemish Beauty	
Beurré Anjou	
Winter Nelis	
Seckel	
Lawrence	

Limited observations of the Gorham in 1936 in southern Ohio indicated that it was doubtful whether Gorham should be classified as one of the most hardy varieties in wood.

The results of the severe winter indicated that Pulteney was relatively hardy in fruit bud. The buds of Phelps, Kieffer, and Conference also seemed to be fairly hardy. The fruit buds of Beurré Bosc were relatively tender.

THE USE OF HARDY STOCKS FOR APPLES

In a few orchards in Ohio apples have been top-worked on hardy root-grafted or "own-rooted" trees, such as Hibernal, Haas, and Virginia Crab. The results in these orchards, as well as results secured in Indiana, Iowa, and Minnesota, where these and other hardy stocks have been used more extensively, indicate that this method is promising. The experimental results vary somewhat in the three states, and certain phases of the practice, such as adaptability of certain varieties to the various hardy stocks, are not definitely known at present. Until more complete information has been secured, definite recommendations cannot well be made regarding the use of hardy stocks for all varieties and under all conditions.

Results in Minnesota indicate that Hibernal is probably the most generally acceptable of the hardy stocks for top-working. One of the most desirable characteristics of Hibernal is its extraordinarily wide-angled crotches. Results at the Indiana Experiment Station indicate that Virginia Crab is most promising as a hardy stock, especially for Grimes Golden. The Virginia Crab in Indiana has been found highly resistant to the collar rot fungus and to fire blight, as well as to low temperatures. Investigators in Iowa, where a large number of hardy varieties have been used, indicate that Hibernal and Virginia Crab seem at present to be the most satisfactory there (14).

Usually these hardy stocks are planted in the orchard, and the scaffold limbs are budded or grafted to standard varieties during the second year of growth. Another method which may be used is that of root-grafting French Crab seedlings to the hardy intermediate stock and then top-working to the desired variety. It seems most satisfactory to graft or bud the standard variety 18 to 24 inches out on the limbs in order to secure hardy crotches as well as trunks. Probably much more definite information will be available in the near future on the use of these hardy stocks in Ohio, for they are beginning to be tried more extensively.

THE REPAIR OF WINTER-INJURED TREES

Whether injured trees recover depends largely on the weather conditions that follow the injury. If all conditions are conducive to the best growth of the trees, recovery of rather severely injured trees may take place. If conditions are not favorable, even slightly injured trees may eventually be destroyed. A standard treatment for all trees following winter injury cannot be given. For example, tacking the bark seems effective in some cases, but in others it is of no value whatever; probably its effectiveness depends largely on the severity and type of injury. Bridge grafting and inarching of the trunks of many injured trees have been exceedingly worthwhile. Scions of hardy varieties only should be used for this purpose. Removing the dead bark and painting the wounds with some material, such as brush grafting wax, water-soluble asphalt tree paint, or white lead and linseed oil, are often helpful in the protection of wounds.

Information on the repairing of winter-injured trees may be obtained from several sources including a recent bulletin by MacDaniels (13) and articles by Beach (3) and Ellenwood and Fowler (8). The methods used in bridge grafting and top-working are described by Lewis (12) in another bulletin of this Station.

SUMMARY AND CONCLUSIONS

From the study of Ohio winters over a period of 167 years, several fairly definite conclusions may be drawn.

There seems to be the same fluctuation in winter temperatures, as well as in fruit tree injury, now as there was 150 years ago. Most climatologists still agree that our climate has not changed and that the winters and summers of the past are good indicators of those of the future.

From the fruitgrower's standpoint there have been 18 severe winters in Ohio as a whole during the last 167 years. This is approximately an average of one every 9 years. At least seven winters during the history of Ohio fruitgrowing may be classified as extremely severe: 1831-32, 1855-56, 1863-64, 1880-81, 1898-99, 1917-18, and 1935-36.

There is a late spring frost that materially affects the fruit crop of the State an average of once every 5 years. Approximately one of every 6 to 7 years can be considered a good fruit year for all fruits throughout the State, based on the history of fruitgrowing in Ohio.

These facts should not be discouraging, but should emphasize that a heavy crop of any fruit every year cannot be expected in the State. There is much yet to learn about the relation of tree hardiness to soil and cultural practices and about the relative value of hardy stocks and varieties.

As a general rule it was noted that the coldest winters were those most destructive to fruits, although there were several exceptions.

MATURITY

Although many factors have been involved in winter injuries, the most important one determining whether a tree is injured at a given temperature has been the degree of maturity (as the term is usually used). In the historical study of winter injury in the State it was found that in at least 7 of the 18

severe winters lack of maturity was the outstanding factor. Immaturity most often results from favorable growing conditions in late summer or early fall. These growing conditions may be results of excessively fertile soil, surplus rainfall, application of large quantities of inorganic nitrogen or manure, recent heavy pruning, or other similar factors that result in much new or unhardened growth. Steinmetz and Hilborn (16), following their artificial freezing tests, state that the "experiments indicated that the injury found after the severe winter of 1933-1934 occurred in November of 1933, and not during the winter months. The definitely nonhardy varieties, such as Baldwin, were injured if frozen during November, but if permitted to harden off they could withstand lower temperatures than ever recorded by authoritative weather records." Certain physiological processes necessary in the maturing of the tree are carried on only when the trees are gradually exposed to low temperatures. If for any reason these processes are upset, the trees will be injured by a much higher temperature than otherwise.

Those trees which were most vigorous and those which were least vigorous during the summer of 1935 were most severely injured (where other conditions were similar). In some instances the old, poorly kept orchards survived the winter more successfully than near-by ones which were well cared for. The poorly grown trees matured their wood early and well and usually bore light crops if any.

TEMPERATURE

As previously suggested, the winters of lowest temperatures have been, with some exceptions, most destructive to fruit trees. No definite "danger point" below which there is likely to be injury can be given, even for a particular fruit. Much depends on other factors. In January 1936 the severity of the injury was directly proportional to the rapidity and magnitude of the drop in temperature, and the degree of injury was usually proportional to the drop below —10 to —14° F. It is well known that the time of occurrence of the low temperatures is an important factor in the amount of injury both to wood and to fruit buds.

CULTURE

Trees growing under systems of continuous and late cultivation went into the winter with their wood growth in an immature condition and were most severely winter-injured. In most years of severe injury it has been definitely noted that the trees in sod or mulch, provided they were not of low vitality, were injured less than those in cultivation. Considerable damage has been done to peach trees by cultivating them thoroughly until late in the season. This seems necessary sometimes, especially in years of heavy crops, to secure the highest yield and best size; nevertheless the effect on the maturing processes should be considered.

SOIL CONDITIONS

In these studies it was clear that trees which had been grown on poorly drained soil were more likely to be winter-injured than those on well-drained locations. Root killing has been fairly common, especially with peaches, and probably injury occurs more often than is realized. In 3 of the 18 severe winters in the history of fruitgrowing in Ohio there has been an unusually large

amount of root injury, especially to peaches. There was also some root injury to apples in 1874-75, 1898-99, and 1903-4. Cover crops, mulches, deep well-drained soil, and other means have been used to avoid this. In only 2 years was it generally noted that trees on high locations were most severely injured; usually the opposite was true. In those 2 years the injury followed high winds, and much root injury was found. In order that the tree may best withstand severe winters it should be grown on deep, well-drained soils and preferably on sites that are well air-drained.

AGE OF TREES

In most of the severe winters old trees were injured more than young ones; however, in 1906-7 young trees (2 to 4 years of age) were evidently injured most. In 1935-36 the older trees suffered more severely in most parts of the State, although in a few localities the reverse was true. Apparently under certain conditions, especially when maturity of wood is of special importance, this situation may occur. The age of the tree, itself, probably is not the deciding factor; it is the condition of the tree that usually accompanies the age. Thus, it seems that an apple tree 40 to 50 years old that is in a vigorous condition is no more or less susceptible to winter injury than one 15 to 20 years of age that is relatively less vigorous.

PRUNING

The time of pruning of the tree fruits has apparently never been emphasized greatly in relationship to susceptibility to winter injury. Following the winter of 1935-36 it was noted definitely that early season pruning was accompanied by injury and that the extent of the injury varied directly with the severity of the pruning. This seemed especially true in young trees.

PREVIOUS CROP

Trees that bore heavy crops of fruit during 1935 were usually more severely injured the following winter than trees that did not bear a crop or those that bore a light one that season. This was an especially difficult factor to study because of the frequent interrelation of other conditions, and the results of the study are only indicative.

INSECTS AND DISEASES

Insects, diseases, or anything responsible for loss of foliage tended to accentuate injury during the following winter. This was especially true of peach trees on Catawba Island in 1903-4 and of cherry trees defoliated by leaf spot previous to the winter of 1935-36.

VARIETIES

Some varieties of all the fruits are more hardy than others, although their relative hardiness each year varies somewhat. There are various types of hardiness, such as hardiness of fruit bud, leaf bud, and wood. A variety may be hardy in one respect but relatively tender in another. This can be determined only by thorough trial. Attention could well be paid to propagation on more hardy root and intermediate stocks for Ohio conditions.

GENERAL

It may be stated briefly that the trees of any given variety which were injured least during the winter of 1935-36 were: (a) relatively young, (b) growing in deep, well-drained soil, (c) growing in soil of moderate fertility, (d) mulched with straw or/and manure previous to minimum temperatures, (e) either not pruned at all or pruned moderately after growth had started in the spring, (f) those which had not borne a crop in 1935 or had borne a moderate to light crop.

WHAT CAN BE DONE TO PREVENT WINTER INJURY

A few practices that may be considered in order to avoid winter injury are:

1. Plant on as frost-free location as possible and in deep soil of moderate fertility.

2. Use sod and mulch systems of culture with moderate fertilizer applications from year to year to keep trees growing well, but not overvegetative. Apply fertilizers in fall or very early spring in order that wood growth may mature properly before winter.

3. Plant on well-drained soil, or drain wet spots in the orchard.

4. Prune trees after severe winter temperatures are over; this is especially desirable for young trees. Confine early pruning when absolutely necessary to light watersprout cutting and light thinning out on older trees.

5. Thin the fruit crops to avoid overloading and weakening of trees.

6. Use mild sprays, thoroughly applied, for control of diseases and insects in order that the foliage may be in the best condition and that tissues may mature properly.

7. Plant apple orchards with more consideration to stocks resistant to cold temperature, at least as far as present knowledge permits. This seems to be accomplished by securing root-grafted trees of Hibernal, Virginia Crab, or other hardy stocks, then budding or grafting the tops to the variety desired after the stocks are well started in permanent locations in the orchard.

8. Plant as hardy varieties as possible consistent with the market demands.

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